Stillwater Sciences

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Technical Memorandum

Date: July 25, 2007
To: Mr. Michael Bowen, Project Manager
From: Yantao Cui, Ph.D., Hydraulic Engineer, John Wooster, Geomorphologist, and Bruce Orr, Ph.D., Senior Ecologist
Re: A first-order estimate of the potential downstream change in suspended sediment concentration in the Klamath River following dam removal

1. Introduction

This memorandum describes an analysis that provides a first-order estimate of the potential downstream differences in suspended sediment concentrations in the Klamath River following dam removal if reservoir drawdown were to start in the months of April, May, June, or July. The analysis is based on geomorphic and hydrologic conditions in the Klamath River, and does not include numerical modeling as part of the analysis. The analysis provides the potential magnitude of suspended sediment concentration at two downstream stations relative to the concentration at Iron Gate Dam (i.e., whether the suspended sediment concentration at the two stations are 10% or 30% of that at Iron Gate). A more detailed analysis of a suspended sediment concentration time series following dam removal will be provided at the conclusion of this study, which will utilize numerical modeling. A conceptual-level estimate of potential suspended sediment concentration immediately downstream of Iron Gate Dam following reservoir drawdown and dam removal is available in GEC (2007).

2. Factors affecting suspended sediment concentration in the downstream direction

A large amount of fine sediment release following reservoir drawdown and dam removal in the Klamath River will result in high suspended sediment concentration downstream of Iron Gate Dam (e.g., GEC 2006, 2007). Based on the analysis of GEC (2006), the majority of the sediment released downstream following reservoir drawdown and dam removal will be fine sediment (primarily silt and clay, with a small fraction of sand and minimal gravel). Due to relatively large discharges and the high channel gradient, the majority of sediment particles will be transported downstream as suspended load (Stillwater Sciences 2004). Two factors may significantly affect the suspended sediment concentration as the high concentration sediment plume travels downstream: (1) dilution due to relatively clean water discharge from tributaries; and (2) settling of suspended sediment due to decreased shear stress. Detailed discussions of these two factors are provided below.

2.1 Dilution due to tributary contribution

There are many tributaries that contribute a significant amount of water discharge into the Klamath River downstream of Iron Gate Dam. Cui et al. (2005), for example, compared flow duration curves at three stations in the river: at Iron Gate Dam (USGS 11516530, river kilometer [RKM] 304), at Seiad Valley

(USGS 11520500, RKM 206), and at Orleans (USGS 11523000, RMK 96), which indicated a significant increase in water discharge with downstream distance (Figure 1). We expect that the substantial influx of clean water discharge will provide a significant dilution of the suspended sediment load as it travels downstream.

2.2 Settling of suspended sediment particles

The combination of three geomorphic and hydrologic characteristics of the Klamath River downstream of Iron Gate Dam prevents significant settling of sediment particles if they are initially transported as suspended load at Iron Gate Dam site (Stillwater Sciences 2004): (1) the gradually increasing discharge as discussed above; (2) a consistently high channel gradient (a reach-averaged gradient of ~ 0.0025) in the downstream direction (upstream of RKM 80); and a nearly invariable bankfull channel width in the downstream direction (upstream of RKM 80) (Figure 2). The combination of these characteristics ensures that bed shear stress increases in the downstream direction, preventing suspended sediment particles from settling out on the channel bed. Due to this conclusion, the potential settling of suspended sediment particles in the downstream direction was ignored in this first-order analysis.

3. Analysis and results

We analyzed the potential suspended sediment concentration at two USGS gauge stations where continuous daily discharge data were collected: at Seiad Valley (USGS 11520500, RKM 206), and at Orleans (USGS 11523000, RMK 96). Because there will likely be no significant suspended sediment settling in the downstream direction as discussed above, the primary factor affecting suspended sediment concentration in the downstream direction will be the increasing discharge. Because suspended sediment concentration is inversely proportional to discharge (assuming the same suspended sediment load), an increase in discharge by a certain factor implies that the suspended sediment concentration will be decreased by approximately the same factor (e.g., if the discharge increases by a factor of 3, the suspended sediment concentration will be decreased by a factor of 3).

Water stored in the reservoirs will be released downstream during reservoir drawdown, and thus, discharge downstream of the dam will be higher than the natural discharge as historically recorded by the hydrologic stations. For this analysis only the storage capacities of Copco 1 and Iron Gate reservoirs need to be considered because J.C. Boyle and Copco 2 dams are scheduled to be removed prior to the removal of Copco 1 and Iron Gate Dams. Copco 1 Reservoir can be lowered to a pool level of 2,585 ft with an associated storage of 26,009 acre-ft before the dam removal reservoir drawdown, and Iron Gate drawdown will starts at the normal pool level of 2,325 ft with an associated storage of 56,550 acre-ft for dam removal reservoir withdraw (based on data in GEC 2006). Thus, there is a combined storage of 82,559 acre-ft of storage between Copco 1 and Iron Gate reservoirs to be released during the reservoir drawdown period. Based on GEC (2006), approximately two weeks will be needed to empty the reservoirs if a 3 ft/day drawdown rate is applied. Discharging the 56,550 acre-ft in two weeks during reservoir drawdown will provide approximately an additional 3,000 cfs discharge during the drawdown period when the major suspended sediment release occurs. Thus, an additional 3,000 cfs discharge was added to the recorded discharge at the Iron Gate (USGS 11516530), Seiad Valley (USGS 11520500), and Orleans (USGS 11523000) stations for the period of reservoir drawdown, and the recorded discharge at the above stations without adjustment was used for the period after the drawdown for the analyses presented below.

The potential dilution factors calculated as discussed above for Seiad Valley and Orleans relative to Iron Gate are provided below. ***The potential suspended sediment concentration values at Seiad Valley and Orleans can be estimated with the estimated suspended sediment concentration at Iron Gate divided by the dilution factors.***

Calculated dilution factor values during and after the drawdown period are presented below for cases where reservoir drawdown occurs in the months of April, May, June, or July.

April: The potential dilution factor at Seiad Valley relative to at Iron Gate for the month of April ranges between 1.1 to 3.6 with a mean value of 1.4 during reservoir drawdown, if the drawdown occurs in the month of April, and ranges between 1.2 and 6.1 with a mean value of 2.0 once the reservoirs are emptied (Figure 3a). Potential dilution factor at Orleans relative to at Iron Gate for the month of April ranges between 1.4 and 7.5 with a mean value of 2.6 during reservoir drawdown period, if the withdraw occurs in the month of April, and ranges between 1.8 and 22.4 with a mean value of 5.0 once the reservoirs are emptied (Figure 3b).

May: The potential dilution factor at Seiad Valley relative to at Iron Gate for the month of May ranges between 1.1 to 2.7 with a mean value of 1.5 during reservoir drawdown, if the drawdown occurs in the month of May, and ranges between 1.2 and 5.8 with a mean value of 2.3 once the reservoirs are emptied (Figure 4a). Potential dilution factor at Orleans relative to at Iron Gate for the month of May ranges between 1.3 and 6.8 with a mean value of 2.7 during reservoir drawdown period, if the withdraw occurs in the month of May, and ranges between 1.7 and 18.2 with a mean value of 5.6 once the reservoirs are emptied (Figure 4b).

June: The potential dilution factor at Seiad Valley relative to at Iron Gate for the month of June ranges between 1.0 to 2.6 with a mean value of 1.4 during reservoir drawdown, if the drawdown occurs in the month of June, and ranges between 1.0 and 6.6 with a mean value of 2.4 once the reservoirs are emptied (Figure 5a). Potential dilution factor at Orleans relative to at Iron Gate for the month of June ranges between 1.1 and 6.1 with a mean value of 2.2 during reservoir drawdown period, if the drawdown occurs in the month of June, and ranges between 1.3 and 17.2 with a mean value of 5.6 once the reservoirs are emptied (Figure 5b).

July: The potential dilution factor at Seiad Valley relative to at Iron Gate for the month of July ranges between 0.9 to 1.9 with a mean value of 1.1 during reservoir drawdown, if the drawdown occurs in the month of July, and ranges between 0.8 and 4.2 with a mean value of 1.6 once the reservoirs are emptied (Figure 6a). Potential dilution factor at Orleans relative to at Iron Gate for the month of July ranges between 1.1 and 3.7 with a mean value of 1.5 during reservoir drawdown period, if the drawdown occurs in the month of July, and ranges between 1.2 and 10.9 with a mean value of 3.2 once the reservoirs are emptied (Figure 6b).

More detailed statistics of the dilution factors at Seiad Valley and Orleans relative to at Iron Gate for the months of April through July are presented in Tables 1 and 2 below.

Table 1. Statistics of the estimated dilution factor during reservoir drawdown at Seiad Valley and Orleans relative to at Iron Gate, based on daily discharge record at the three stations for the period of WY 1961 and 2006, and the estimated extra discharge of 3,000 cfs from reservoir drawdown.

Exceedance Probability (%)		10	20	50	80	90
Seiad Valley	April	1.6	1.5	1.4	1.3	1.2
	May	1.8	1.6	1.5	1.3	1.2
	June	1.7	1.6	1.3	1.2	1.1
	July	1.3	1.2	1.1	1.1	1.0
Orleans	April	3.5	3.1	2.5	2.1	1.9
	May	3.7	3.2	2.5	2.1	1.8
	June	3.1	2.7	2.0	1.6	1.4
	July	1.8	1.6	1.4	1.3	1.2

Table 2. Statistics of the estimated dilution factor following the emptying of the reservoirs at Seiad Valley and Orleans relative to at Iron Gate, based on daily discharge record at the three stations for the period of WY 1961 and 2006.

Exceedance Probability (%)		10	20	50	80	90
Seiad Valley	April	2.5	2.2	1.9	1.6	1.5
	May	3.2	2.7	2.2	1.8	1.7
	June	3.8	3.0	2.2	1.7	1.5
	July	2.3	1.9	1.5	1.3	1.2
Orleans	April	7.4	6.3	4.5	3.3	3.0
	May	8.4	7.0	5.2	3.8	3.3
	June	9.4	7.3	4.9	3.5	2.9
	July	4.9	4.0	2.9	2.3	2.0

4. How to use estimated dilution factor values presented above

The dilution factors provided in Figures 3 through 6 and in Tables 1 and 2, in conjunction with an estimate of potential suspended sediment concentration at Iron Gate, can be used to estimate potential suspended sediment concentration at Seiad Valley and Orleans following reservoir drawdown if the drawdown were to occur in the months of April, May, June, or July under the assumption that Copco 1 and Iron Gate reservoirs would be drawn down at a rate of approximately 3 ft/day. A conceptual level estimate of potential suspended sediment concentration at Iron Gate Dam following reservoir drawdown can be found in GEC (2006) and GEC (2007). In GEC (2006) for example, the suspended sediment concentration at Iron Gate Dam was estimated as high as 20,000 ppm if reservoir drawdown started on October 1. This value can be considered as a conceptual level estimate of suspended sediment concentration at Iron Gate if reservoir drawdown were to occur in the months of April through July because the inflow to the reservoirs following October 1 is similar to that which normally occurs in the months of April through July. Using an estimated suspended sediment concentration of 20,000 ppm at Iron Gate, we can estimate the suspended sediment concentration at Seiad Valley and Orleans using the dilution factors presented in Figures 3 through 6 and in Tables 1 and 2. For example, as a first order estimate, we expect that, if reservoir drawdown were to occur in the month of April, suspended sediment concentration at Orleans during drawdown period would have an 80% probability of being approximately 10,000 ppm or less (i.e., Table 1 and Figure 3a indicate there is an 80 % probability that the dilution factor for Orleans in April will be 2.1 or greater, so the estimate of 20,000 ppm sediment concentration at Iron Gate is divided by the dilution factor of 2.1 to yield the estimate of approximately 10,000 ppm at Orleans). Conversely, there would be a 20 % probability that the dilution factor would be less than 2.1, in which case sediment concentration at Orleans would be greater than 10,000 ppm (but would not exceed an estimated maximum concentration of 14,250 ppm since the minimum dilution factor for Orleans in April during drawdown period is 1.4).

5. References

Cui, Y., Braudrick, C., and Rothert, S. (2005) Preliminary Assessment of Sediment Transport Dynamics Following Dam Removal: A Case Study, *Proceedings (CD)*, EWRI Watershed Management Conference, Williamsburg, VA, July 19-22, 2005.

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Gathard Engineering Consulting (2007) Evaluation of Alternatives to Reservoir Lowering Start Date from Those Proposed in December 2006 Federal Energy Regulatory Commission Report, *Technical Memorandum*, 40031st Ave NW, Seattle, WA, November.

Stillwater Sciences (2004) A Preliminary Evaluation of the Potential Downstream Sediment Deposition Following the Removal of Iron Gate, Copco, and J.C. Boyle Dams, Klamath River, CA, *Final Report*, prepared for American Rivers, 409 Spring Street, Nevada City, CA 95959, 34p.

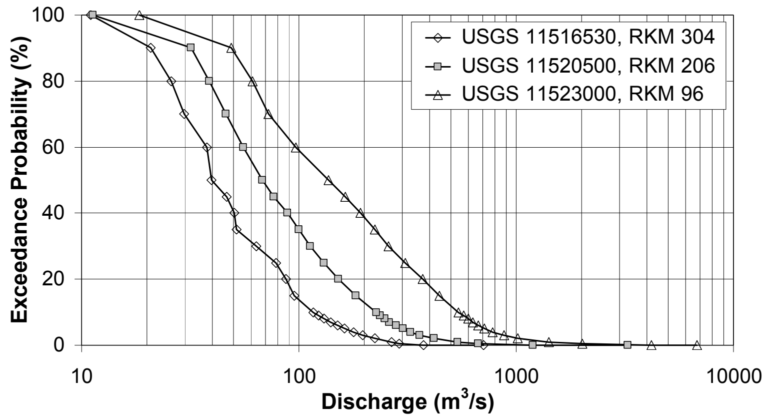


Figure 1. Comparison of flow duration curves at three USGS gauge locations (based on daily average discharge records between 10/1/1960 and 9/30/2002), indicating increased discharge in the downstream direction (Cui et al. 2005).

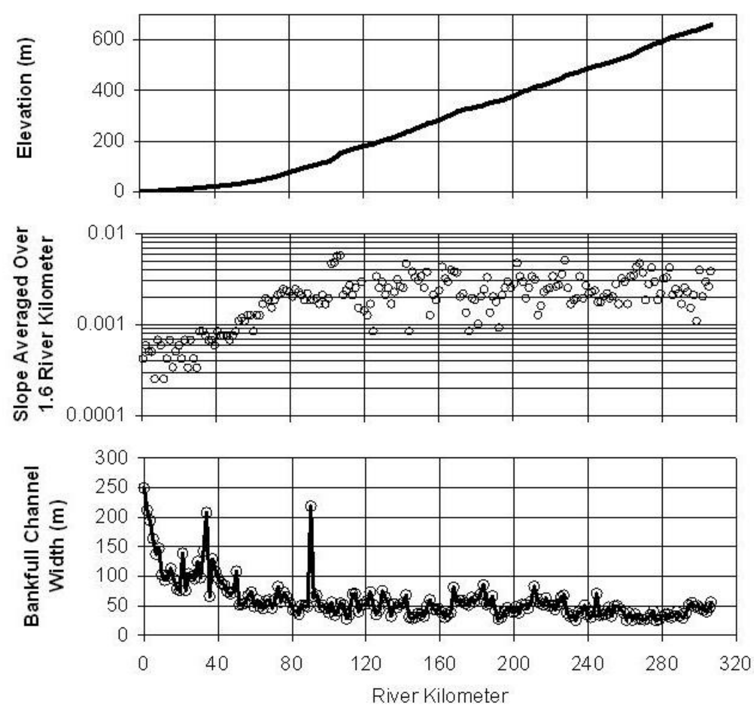


Figure 2. Longitudinal profile, reach average slope, and bankfull width of the Klamath River. Longitudinal profile and slope are based on a 1951 topographic survey presented in Ayres Associates (1999), and bankfull channel widths were first read from the 1:7,500 scale aerial photographs and then interpolated to 1.6-km spacing.

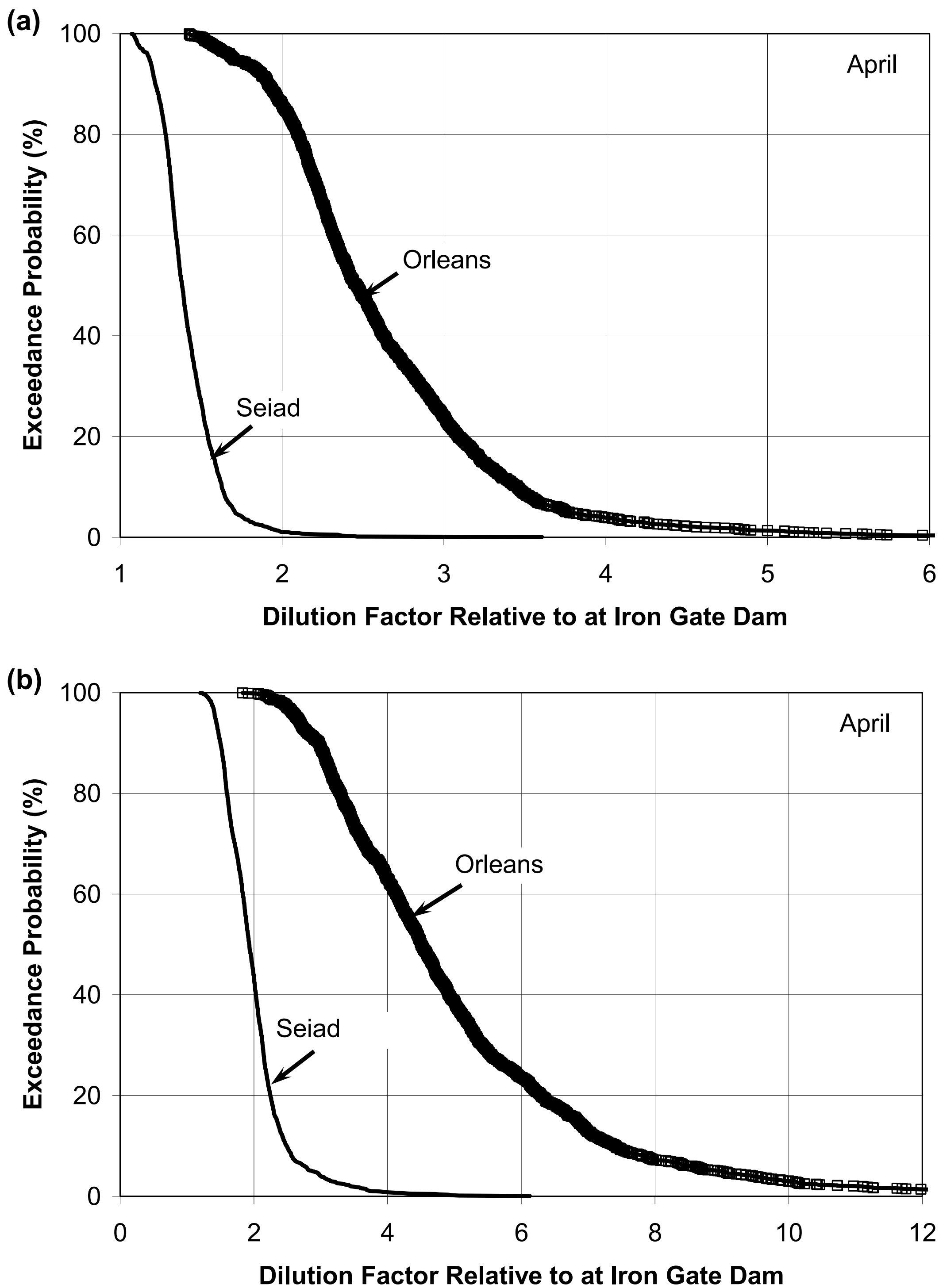
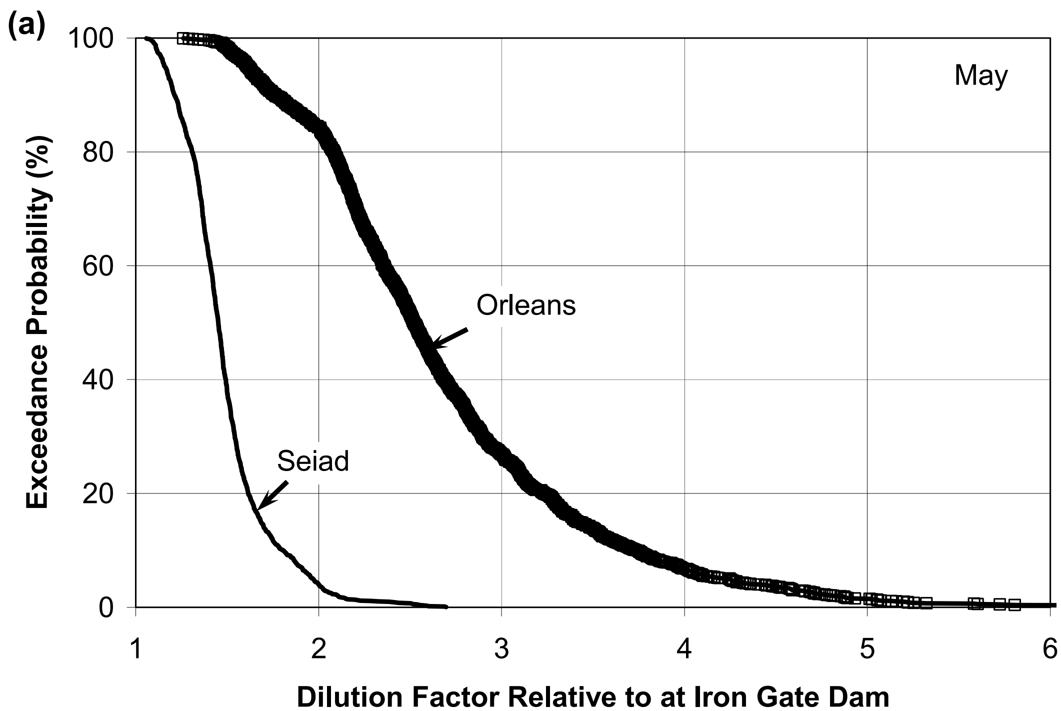


Figure 3. Estimated dilution factor at Seiad Valley (RKM 206) and Orleans (RKM 96) relative to at Iron Gate (RKM 304) for the month of April: (a) During reservoir drawdown if drawdown starts in the month of April; and (b) After the reservoirs are emptied.



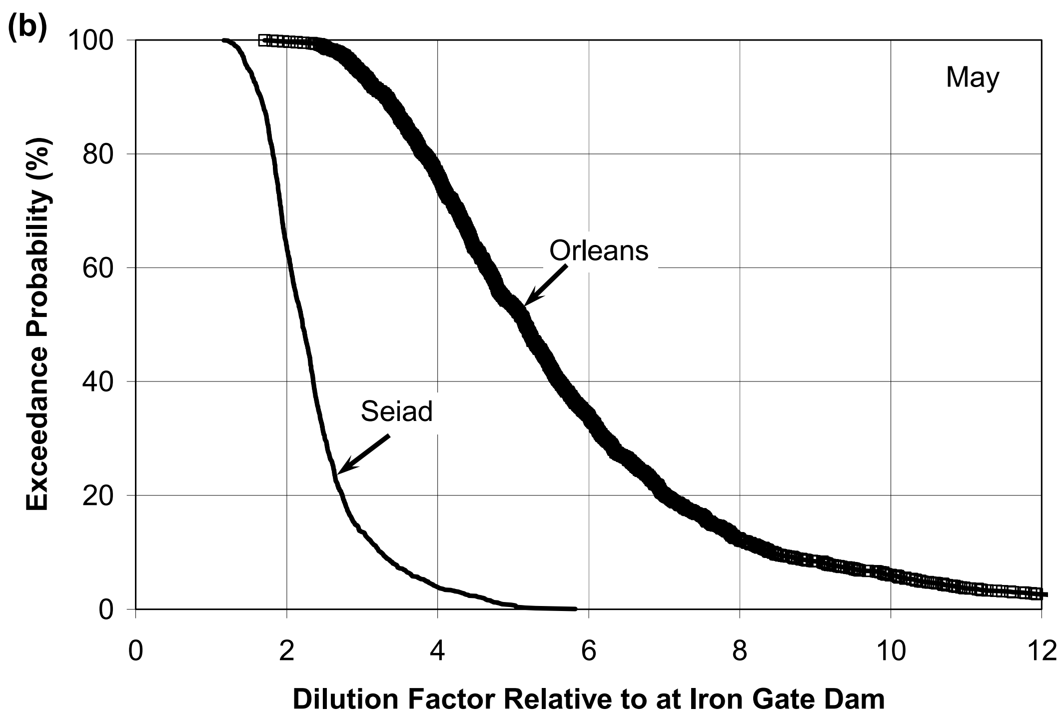


Figure 4. Estimated dilution factor at Seiad Valley (RKM 206) and Orleans (RKM 96) relative to at Iron Gate (RKM 304) for the month of May: (a) During reservoir drawdown if drawdown starts in the month of May; and (b) After the reservoirs are emptied.

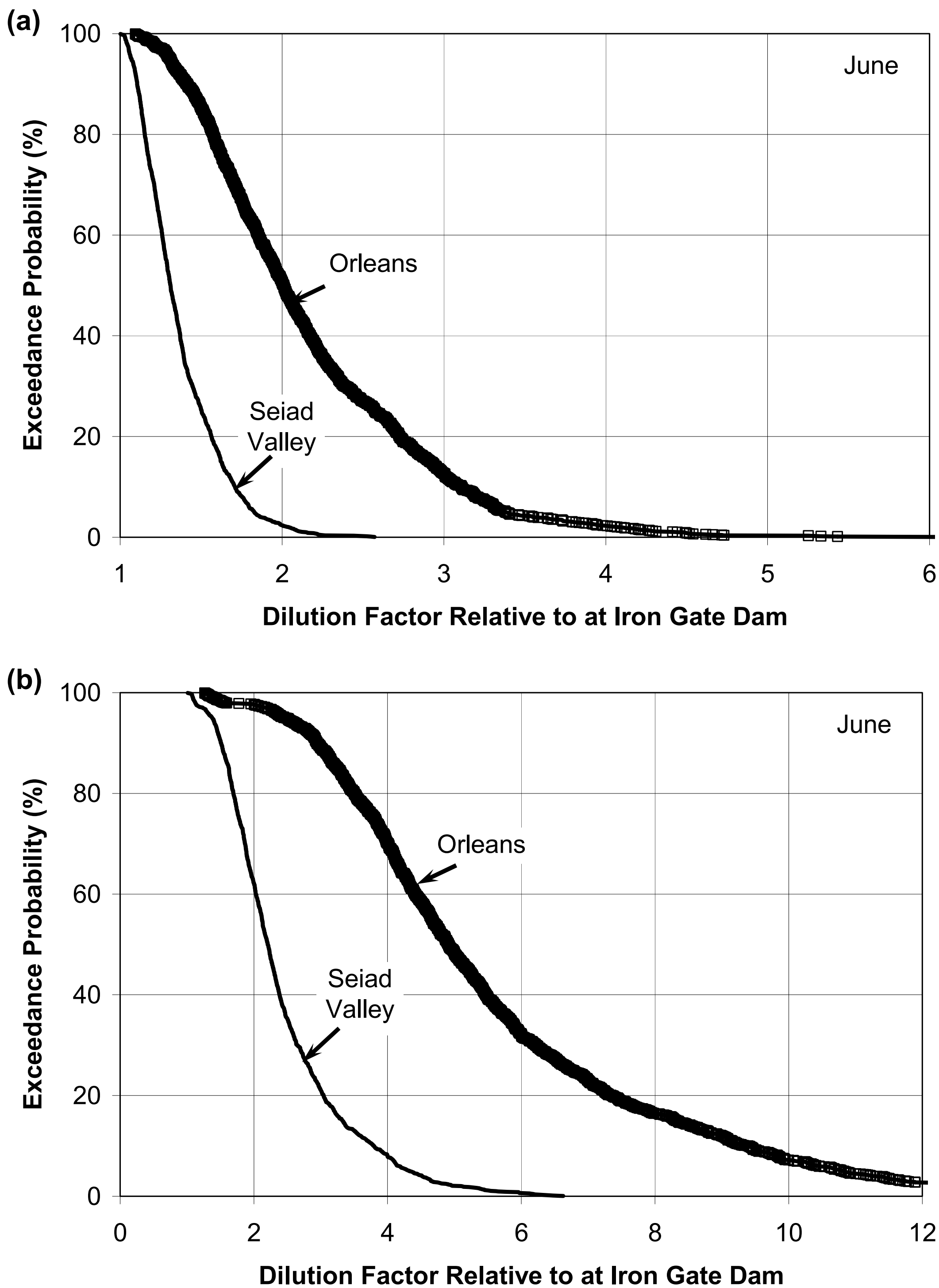


Figure 5. Estimated dilution factor at Seiad Valley (RKM 206) and Orleans (RKM 96) relative to at Iron Gate (RKM 304) for the month of June: (a) During reservoir drawdown if drawdown starts in the month of June; and (b) After the reservoirs are emptied.

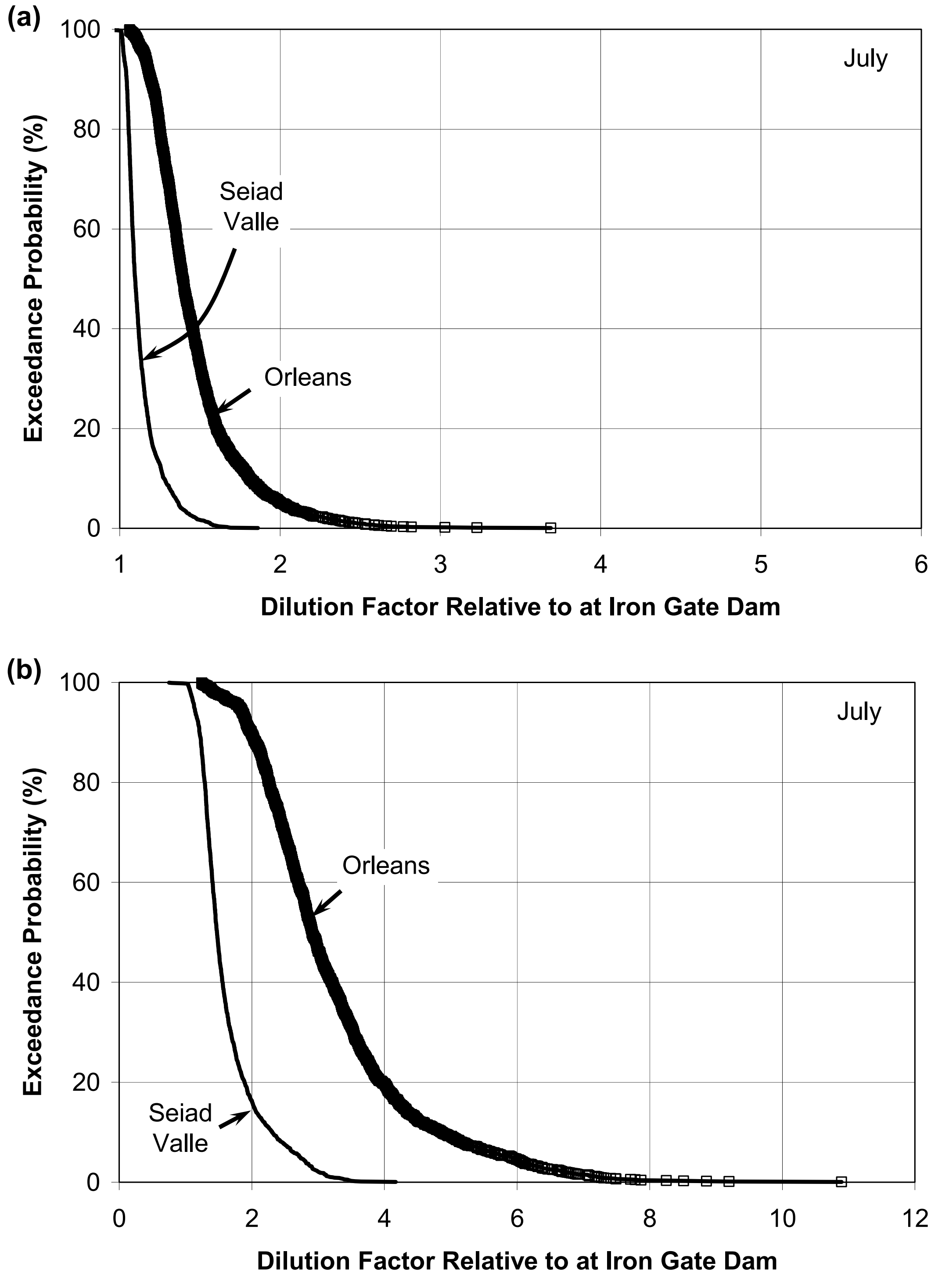


Figure 6. Estimated dilution factor at Seiad Valley (RKM 206) and Orleans (RKM 96) relative to at Iron Gate (RKM 304) for the month of July: (a) During reservoir drawdown if drawdown starts in the month of July; and (b) After the reservoirs are emptied.